Novel Aspheric Optical Manufacturing Approaches

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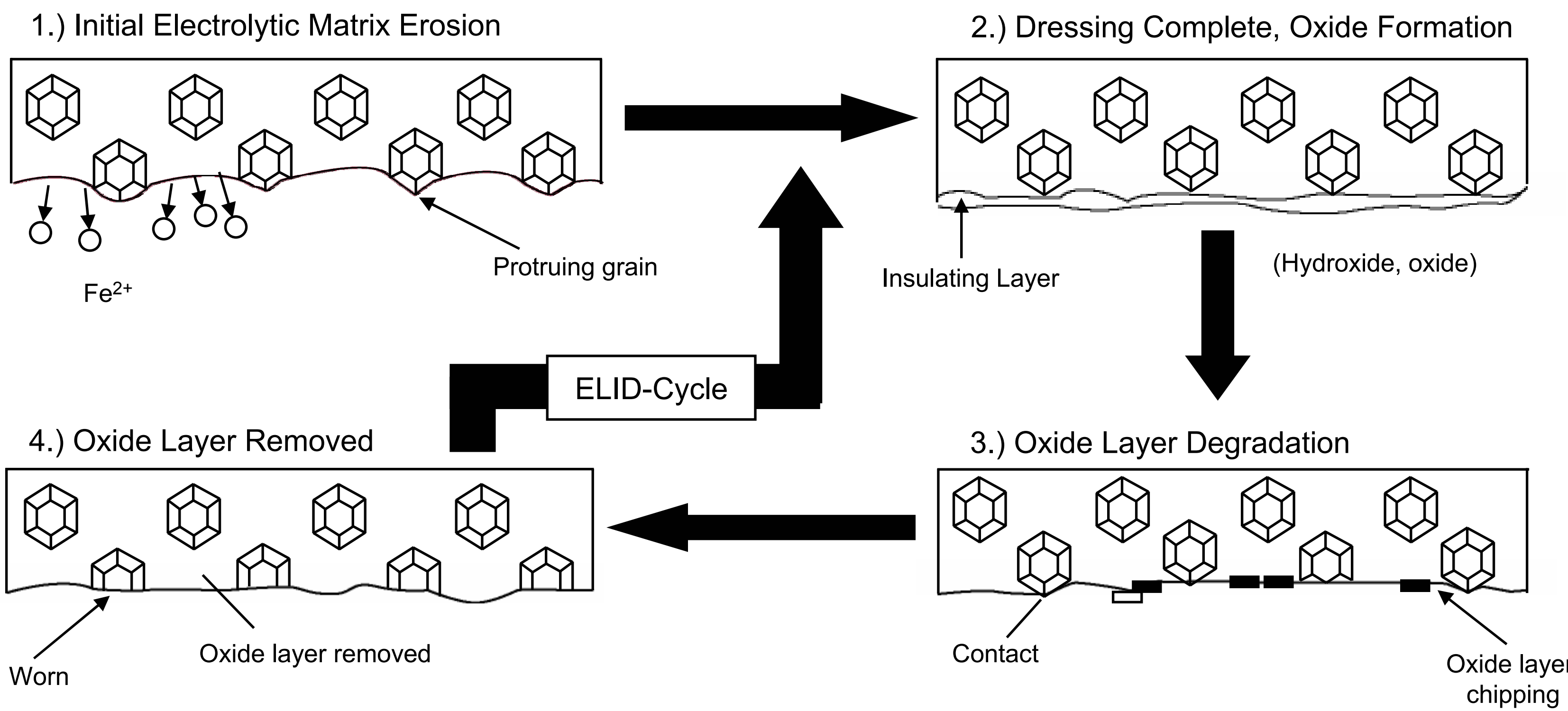
SBIR Activities

- CCOS of Bare Beryllium Aspheric Optics
  – NASA Contract #NAS8-03036
  – TPOC: Dr. Phil Stahl, NASA/MSFC
- Carbon Nanotube Single Point Turning of SiC Optics
  – MDA Contract #FA8650-04-M-4219
  – TPOC: Dr. James Foshee, AFRL/IFGD
- Stressed Mirror Polishing of Large Optics
  – MDA Contract #FA9453-04-M-0263
  – TPOC: Dr. Brett deBlonk, AFRL/VSSV

CCOS of Bare Beryllium Aspheric Optics

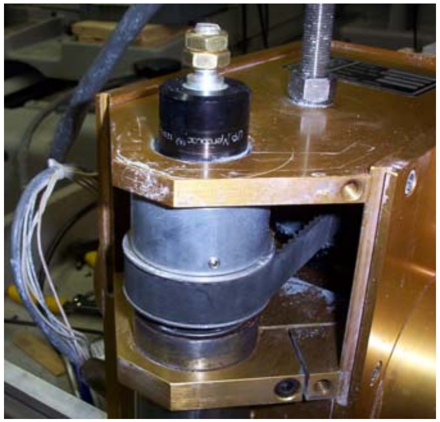
- CCOS of Bare Beryllium Aspheric Optics Phase II
  - NASA Contract #NAS8-03036
  - TPOC: Dr. Phil Stahl, NASA/MSFC
- CCOS grinding and polishing of bare beryllium has been successfully demonstrated by Tinsley for a number of space-based telescope applications
  - SBMD, AMSD, SIRTF, FEWS, GSTS
- Grinding of bare beryllium is made difficult by the hardness and brittleness associated with beryllium
- Electrolytic In-Process Dressing has been applied successfully to metal surface grinding
  - In-situ tool dressing improves grinding efficiency
- ***SBIR activity conducted to apply similar in-situ tool dressing techniques to improve the material removal rate and uniformity associated with the CCOS grinding of beryllium***
  - ***Potential Process Improvements: (1) improved grind material removal rates; and (2) improved uniformity of grind rate over time***

ELID/EDM Overview

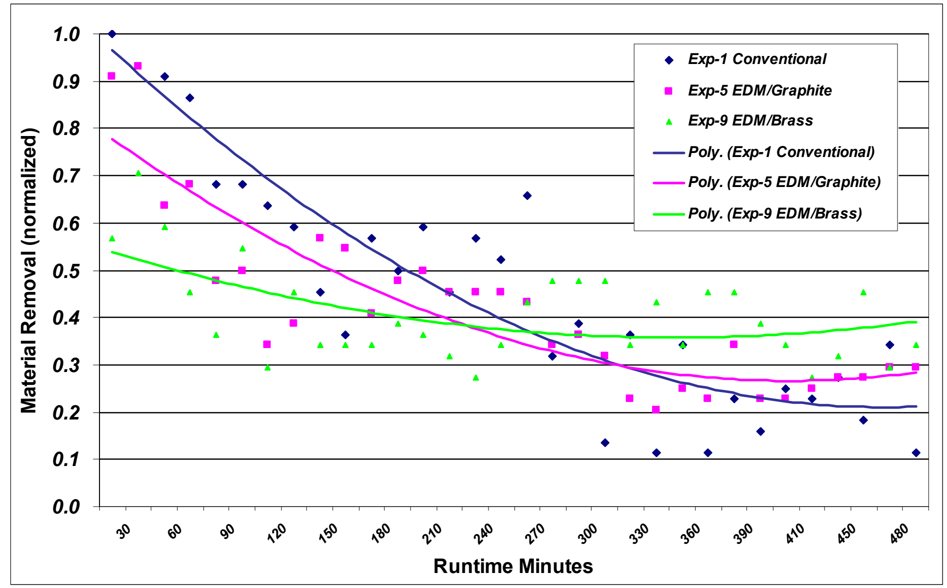


- Over time wear of abrasive grains and oxide layer on grinding tool surface result in changes in material removal characteristics
- Wear of oxide layer increases electo-conductivity of tool
- ELID processing takes advantage of this change in conductivity
  - Resulting increase in electrolysis recovers the oxide layer
  - Material removal characteristics are kept constant with in-situ dressing

Summary of Phase I Results



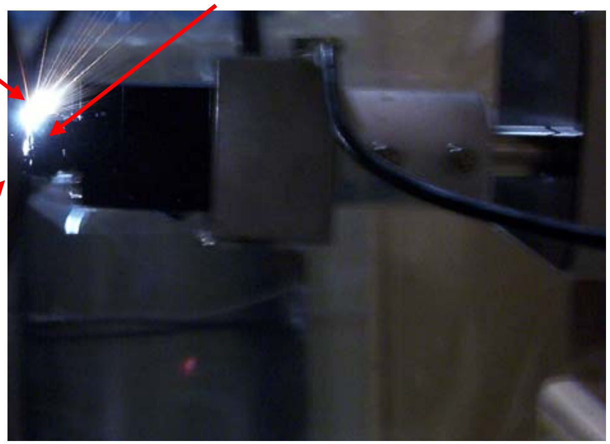
Modified CCOS Spindle



Graphite Electrode

EDM discharge

Grinding Tool



EDM dressing of copper/diamond grinding tool with graphite electrode

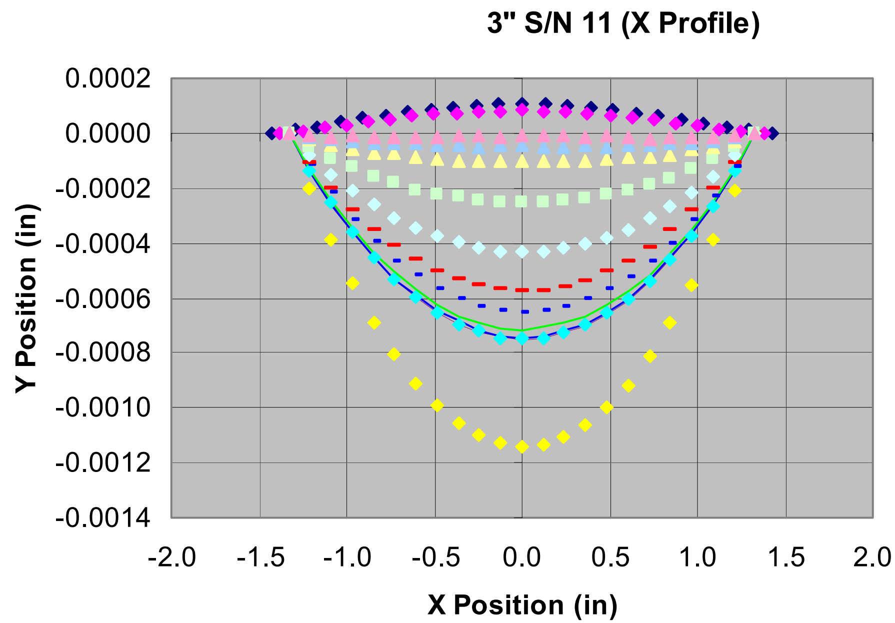
- EDM selected as baseline dressing approach
- Copper Resin grinding tool matrix selected
- Dionized water selected as EDM fluid
- Graphite and Brass electrodes evaluated
- EDM process demonstrated to improve uniformity of CCOS material removal rate over time on bare beryllium (O30)

Phase II Status

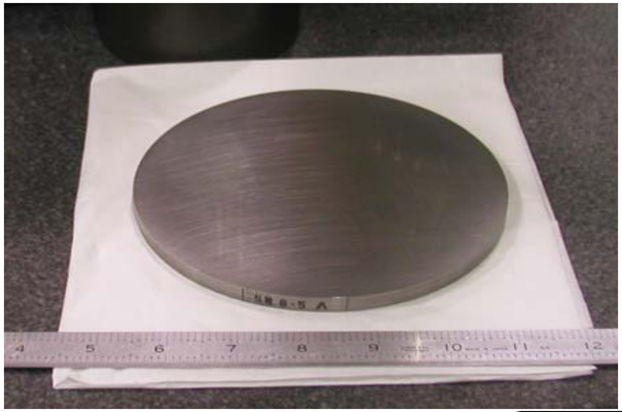
- EDM in-situ tool dressing work ongoing
  - EDM/CCOS grinding head has been improved
    - New bearings/seals
  - Additional work done on 150 mm diameter O30 substrates with the goal of developing a more uniform, repeatable process
    - Vary grinding parameters
    - Vary EDM parameters
      - Voltage, current, duty cycle
  - Currently evaluating upgraded power supply options
- Phase II scope expanded to cover a wider range of processing parameters which impact CCOS grinding of beryllium
  - Detailed removal rate studies as a function of processing parameters
    - Grit size, pressure, speed
  - Stress layer thickness as a function of processing parameters
  - Stress relieving studies
- Phase II work is being done in coordination with AMSD/JWST work with a goal of transferring technology development directly into JWST production facility

Typical Phase II Processing Evaluation: Mirror Stress Compensation

- Grinding of mirror may produce a shape change in substrate (change is 95% focus type change)
- Small samples used to quantitatively predict change, allowing for subsequent shape compensation
- Profiles of thin disks characterized as a function of process step
- Critical information for accurate process planning



Stress Induced Deformation for Various Processing Parameters

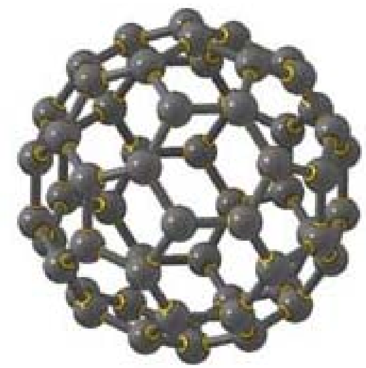


Carbon Nano-tube Single Point Turning of SiC Aspheres

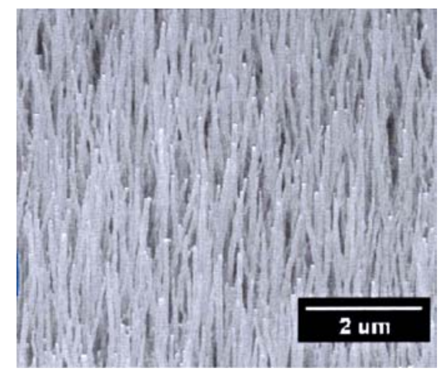
- CNT turning of SiC aspheric optics Phase I
  - MDA Contract # FA8650-04-M-4219
  - TPOC: Dr. James Foshee, AFRL/IFGD
- Tactical applications require new/innovative manufacturing processes in order to produce high quality aspheric optics, in hard materials, at low costs
  - Single point diamond turning of metal optics common for tactical applications
  - Single point diamond turning not viable for SiC materials which are being proposed for future MDA applications
- Carbon Nano-tube based structures have been demonstrated to provide unsurpassed hardness
- ***SBIR activity conducted look at the viability of single point turning of SiC optical surfaces with CNT-based, "superhard" materials***
  - ***Objective: demonstrate a manufacturing process with the time/cost advantages associated with single point turning of metal optics in a SiC material***

Carbon Nano-Tube (CNT) Materials

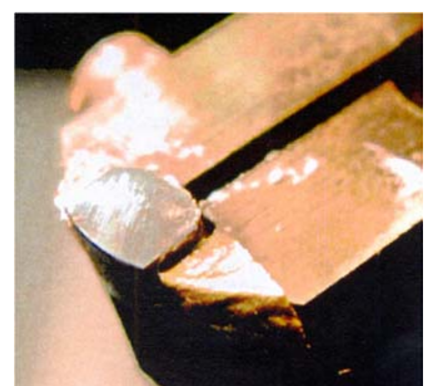
- Carbon Nano-tubes (CNTs) produced by consolidation of C_{60} fullerene
  - Fullerenes are the 3rd major from of pure carbon
  - Symmetry results in unsurpassed hardness
  - Macroscope CNT structures built up by consolidation of fullerenes
    - Axial Young's Modulus of > 1 TPa
    - Strength predicted at 130 GPa
    - 2x – 6x more abrasion resistant than diamond
  - CNTs retain other material properties desired for single point turning
    - High lubricity
    - Low CTE
    - High thermal conductivity



C_{60} Fullerene



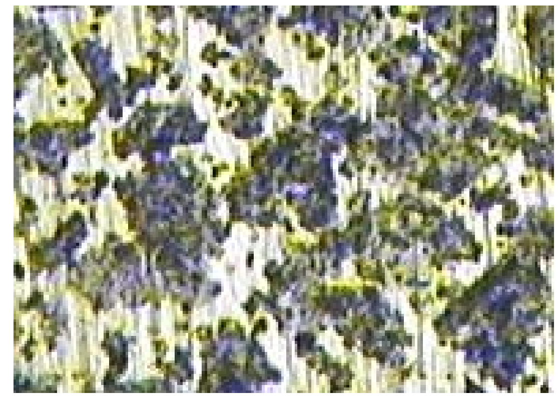
Carbon Nanotubes created from Fullerene consolidation

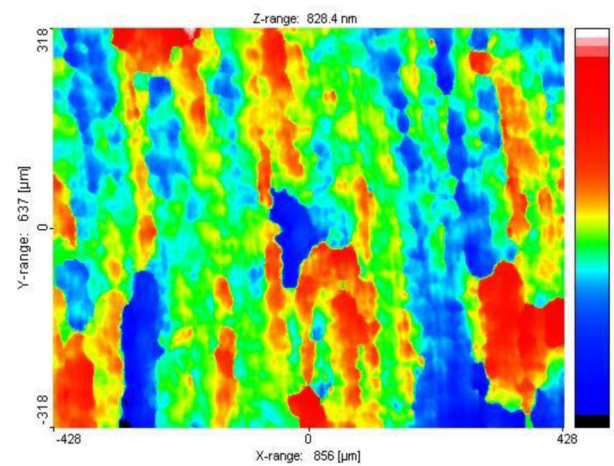


Cutting tool produced from polished carbon nanotube

Single Point Turning of SiC at Tinsley

- Tinsley conducted tests with lathe turning of Reaction Bonded SiC
  - The ability to single point turn SiC does not currently exist
  - Knoop hardness > 2000 kg/mm^2
- DMI/CNT based material successfully cut SiC but with considerable tool wear
  - Cut depths of 100 – 500 μinches done with two different tools
  - Considerable tool degradation seen
    - Significant sagitta wear after 500 linear feet of cutting
  - Surface roughness limited due to tool chatter
    - Approx 200 nm RMS roughness after turning





Tinsley result confirms the ability of these superhard materials to single point turn materials that had previously been thought too hard/abrasive to cut

Stressed Mirror Polishing of Large Aspheric Optics

- Stressed Mirror Polishing of Large Aspheric Optics Phase I
  - MDA Contract # FA9453-04-M-0263
  - TPOC: Dr. Brett deBlonk, AFRL/VSSV
- Stressed mirror polishing (SMP) has been proven a viable, low-cost, high speed optical fabrication process
  - 10's of 2 meter glass aspheres produced for Keck using SMP
- Process is suitable for simple "slab" optical shapes, more challenging for lightweighted mirror geometries
- ***SBIR activity to assess the viability of stressed mirror polishing over a wide range of application areas***
  - ***Ground based segmented telescope applications (Thirty-meter-telescope), airborne optical systems (Airborne Laser), space based telescope concepts (future JWST-like segmented systems)***

Rational For Stressed Mirror Polishing Approach

Traditional aspheric optical polishing requires significant amounts of iterative, manual polishing by skilled opticians

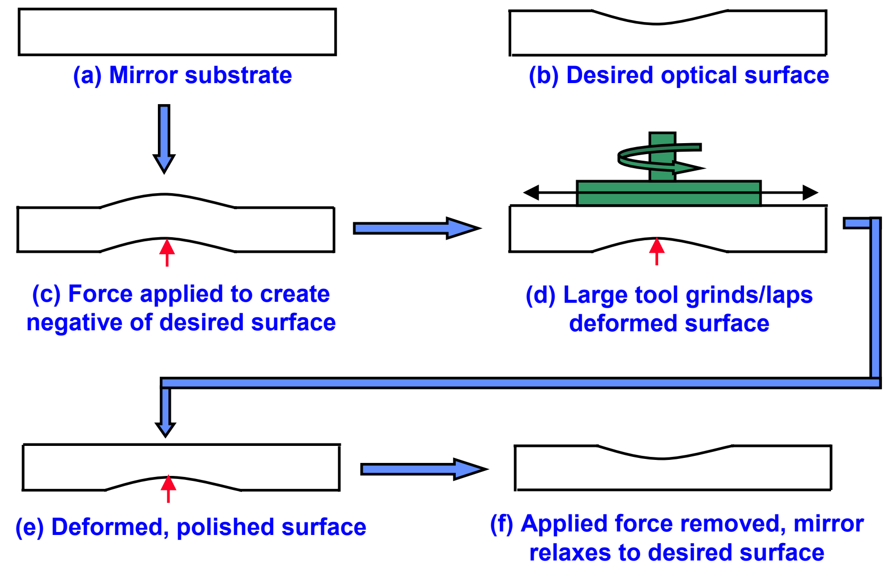
Computer Controlled Small Tool Polishing is applied to minimize the amount of “touch” labor required for aspheric optics fab

- Traditional Mirror Fabrication Process/Issues
  - Aspheric optical grind/polishing process is slow, iterative process
    - Traditional polishing with skilled opticians can take many man-years of labor
    - Computer controlled small tool polishing improves the convergence of the process
      - Limited material removal from small tool footprint not consistent with “rapid” fabrication of meter-class mirrors

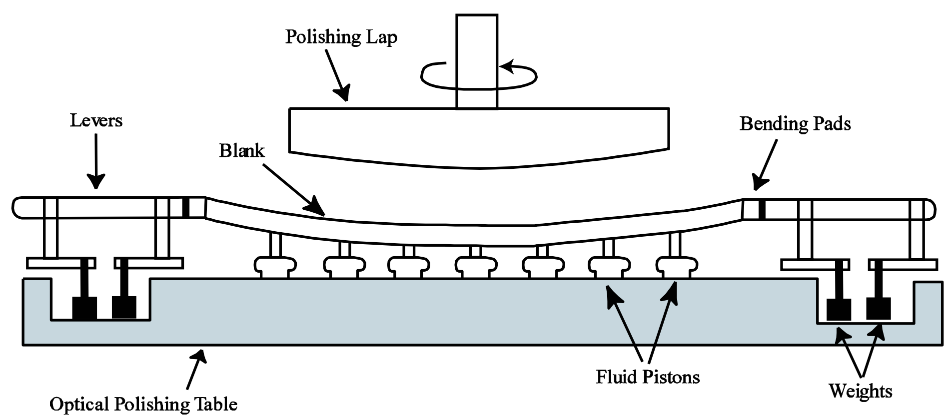
Stressed Mirror Polishing (SMP) Overview

<u>Stressed Mirror Polishing Methodology</u>

- Stressed mirror polishing allows the polishing of aspheric optical surfaces using a large spherical polishing tool
  - Greatly increasing material removal rates (10x – 50x)
- Off axis parabolic/elliptical mirrors have aspheric departures which consist almost entirely of defocus, astigmatism and coma
- These shapes can be introduced into a mirror substrate by way of elastic deformation
- During SMP forces are applied to the mirror substrate to deform it into a shape which is the negative of the desired aspheric surface
- While in its deformed shape the mirror is polished with a large spherical grinding/polishing tool
- When stresses are removed the mirror relaxes back into the desired aspheric surface shape



Notional Stressed Mirror Polishing Flow



Large Tool Stressed Mirror Polishing Schematic

SMP of Lightweighted Mirror Substrates

- Phase I SBIR Activities/Plans
  - Review the viability of stressed mirror polishing of lightweighted mirror substrates
    - Vary mirror size, off axis distance, F-number, areal density and material
  - Review viable range of aspheric departures
  - Review residual surface error after stressed mirror polishing

Summary

- Three novel aspheric optical manufacturing technologies currently being evaluated/developed under three separate SBIR contracts
  - Improve material removal characteristics of Tinsley's CCOS process by development/implementation of an in-situ EDM based dressing technology
  - Reduce cost of SiC aspheric optical manufacturing by application of "superhard" carbon-nanotube based cutting tools in a single point turning configuration
  - Reduce the time/cost associated with large aspheric optical manufacturing by application of a stressed mirror polishing methodology